

Sulfur Emission: Control Technology and
Waste Management

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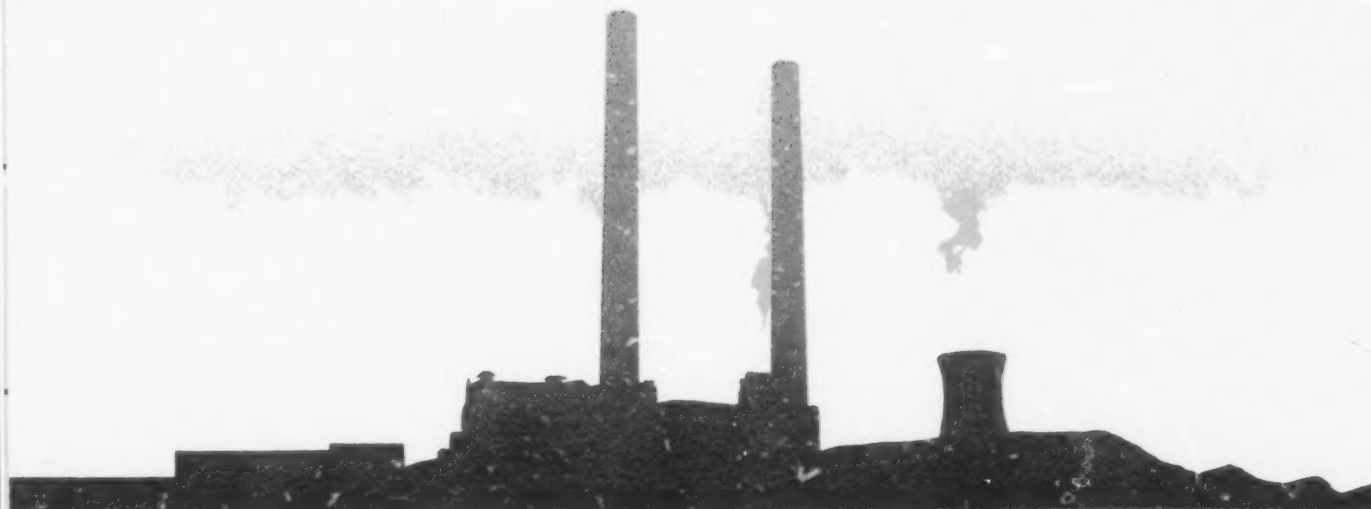
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Decision Series



**sulfur
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**& waste
management**

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sulfur oxide pollution

The world's industrialized societies are responsible for massive amounts of sulfur oxide pollutants being discharged into the atmosphere each year — about 65 million tons. Three quarters of that amount comes from one percent of the global surface area, namely, from central and northeastern United States, southern Canada, and northern Europe. Another 35 million tons come from natural sources, such as volcanoes, which are generally remote from human habitation. Increasing worldwide demand for energy, derived mainly from the burning of fossil fuels, will make this situation even worse by the year 2000.

Most of this pollution comes from the combustion of coal that contains sulfur as a natural contaminant. The U.S. will be burning more coal in the future in order to decrease its dependency on foreign oil. Consequently, the nation will be faced with more severe air pollution problems in the years ahead.

Sulfur dioxide (SO_2), which is the main pollutant, has been found to irritate the respiratory tract and can cause permanent injury to the lungs. People with chronic pulmonary disease or cardiac disorders, the young, and the elderly are most susceptible to SO_2 pollution. During an air pollution episode in Donora, Pennsylvania, in 1948, high levels of SO_2 in combination with other pollutants resulted in a significant increase in the death rate.

Sulfur dioxide and its related pollution have also been implicated in loss of labor productivity. For example, a recent estimate is that the reduction of urban air pollution by 60 percent over the 1970 levels would result in an economic savings of between 16 and 34 billion dollars.

Small sulfate particles are the major cause of reduction in visibility in the eastern United States. On an average summer day, visibility has decreased from 15 to 8 miles over the last 25 years.

Much of this sulfur dioxide, when exposed to moisture in the atmosphere, oxidizes into acidic sulfates (H_2SO_4), which are then deposited in the form of acid rain. The acid rain problem was first recognized in Scandinavia. Swedish scientists found steady increases of sulfur and nitrogen compounds in rain and snowfall, along with a closely correlated increase in acidity. Since World

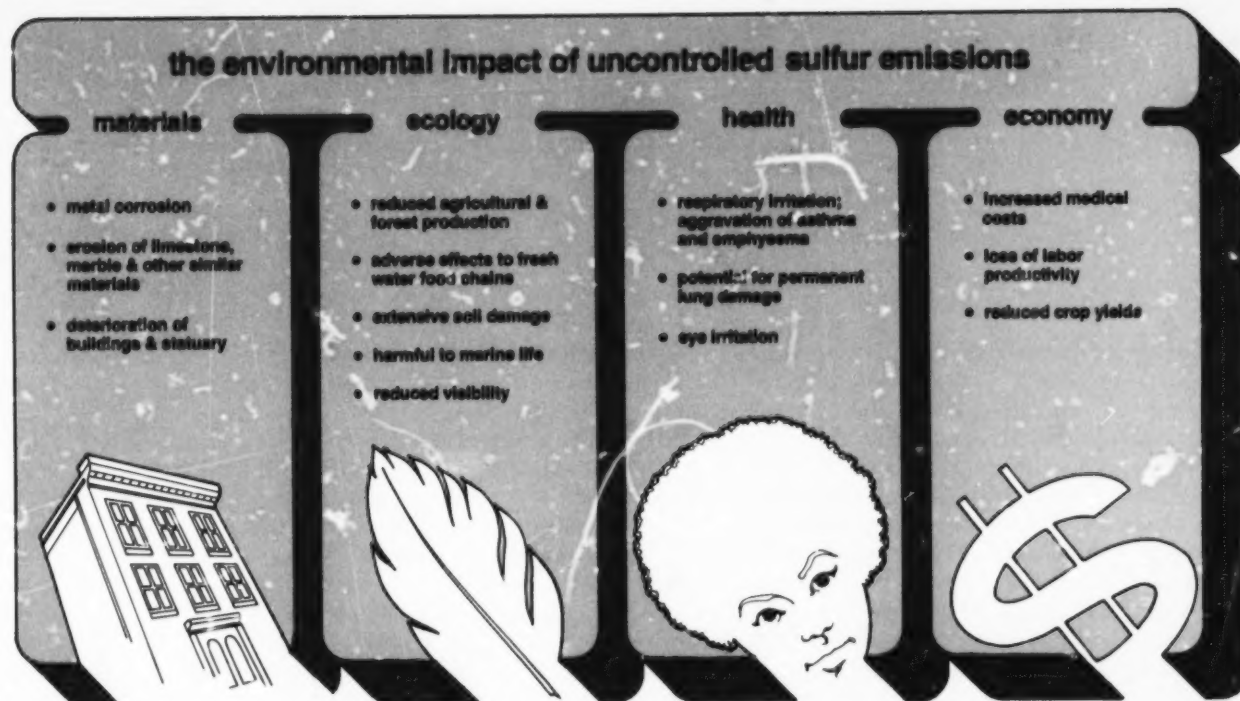
War II, the average acidity of precipitation in Scandinavia and in the northeastern U.S. has increased significantly — from about 10 to almost 100 times the acidity of normal rainwater.

The acid rain impact is not necessarily confined to the locality where the sulfur dioxide is emitted. Only about one-third of the total acid rainfall in Scandinavia can be attributed to local emissions. About one-half comes from other European sources, and there is the possibility that at least a part of the rest originates in North America.

Although the impacts of acid precipitation have not been fully evaluated, studies in Europe, Canada, the U.S.S.R., and the northeastern United States have shown a number of adverse effects. Acid rain is believed to be the cause of declines in present forest and agricultural productivity.

Acid conditions in lakes or streams often cause failure in fish spawning, particularly for trout and salmon species. The most strongly affected areas tend to be high altitude forest streams and lakes, such as the acidified lakes in the Adirondack Mountains. This suggests a serious long-range threat to many of our national parks.

Depletion of nutrients from soils and streams is another problem caused by acid rain. This problem involves subtle but important mechanisms by which the ecosystems are damaged. Research is now being done to determine effects on agriculture.



In addition to these ecological impacts, acidic sulfates corrode and deteriorate materials such as metals, limestone, marble, roofing slate and mortar.

Some of civilization's greatest art and archaeological treasures have resisted deterioration for thousands of years. However, in recent years they have become severe casualties of society's sulfur dioxide emissions. One example is the once gleaming, white-marble Taj Mahal, which has been stained and damaged by industrial pollution. Sulfur oxide fumes from a giant refinery being built 60 miles north of the Taj Mahal could be an increased threat to this architectural wonder.

sources and growth

Most industrial sulfur pollution comes from coal-burning, electric-power generating plants. These power utilities account for nearly 70 percent of the society generated sulfur dioxide emissions in the U. S., with the rest coming from industrial sources and from residential/commercial heating systems.

Increases in SO_2 emissions are thus closely tied to the rapidly expanding electric power industry, which since 1950, has doubled its electrical output every 10 years. An indication of the potential pollution problem can be seen in the massive growth projected in electricity generation in the U. S. Approximately 300 new fossil-fuel-fired power plants are expected to begin operation within the next 10 years. Associated with this growth is the continued long-term increase in utility coal consumption from 405 million tons per year in 1975 to between 800 and 1,300 million tons per year in 1995. This power growth is expected to increase power plant SO_2 emissions from 18.6 million tons per year in 1975 to 20.6 million tons per year in 1995.

The present control strategy for new and

existing power plants will only slow down the rate of growth in SO_2 emissions; it will not necessarily decrease the total emissions below their current level. Although controls are expected to limit emissions from electric utilities, increases are expected as a result of growth in other industrial combustion sources, as new and existing facilities increasingly turn to coal for their primary fuel.

While all of these projections are subject to a number of assumptions — expected growth rate of new sources, degree of control required for these sources, degree of compliance with control requirements for existing sources, and changes in regulatory requirements — they nevertheless illustrate the growing stress on our environment from sulfur dioxide pollution. Civilization's growing appetite for more energy will continue to require greater amounts of fossil fuels to be burned. Worldwide use of coal during the brief 30 year period from 1940 to 1970 was approximately equal to that consumed in all preceding history. In the U.S., increased usage of coal is called for in the future under the National Energy Plan. Increased combustion of coal and the associated generation of sulfur oxide pollutants will impose a continuing need to ensure protection of public health and the quality of our environment.

control requirements

The major national driving force for sulfur oxide control is the Clean Air Act originally enacted in 1970. Under this Act, the Environmental Protection Agency (EPA) established New Source Performance Standards (NSPS) for new facilities and for any major modification to existing facilities. The present NSPS limits SO_2 emissions from coal-fired plants to 1.2 pounds per million British Thermal Units (BTUs) of heat

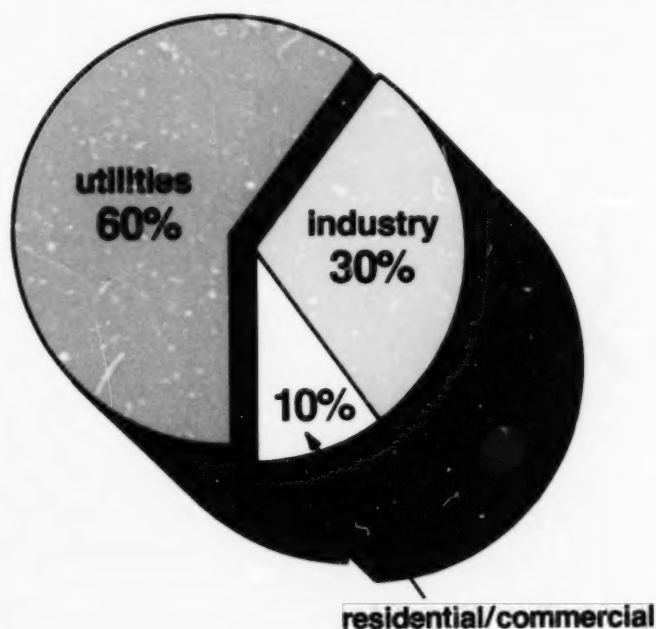
generated. This limit requires about a 75 percent reduction in SO_2 emissions for combustion of coal with a 3 percent sulfur content.

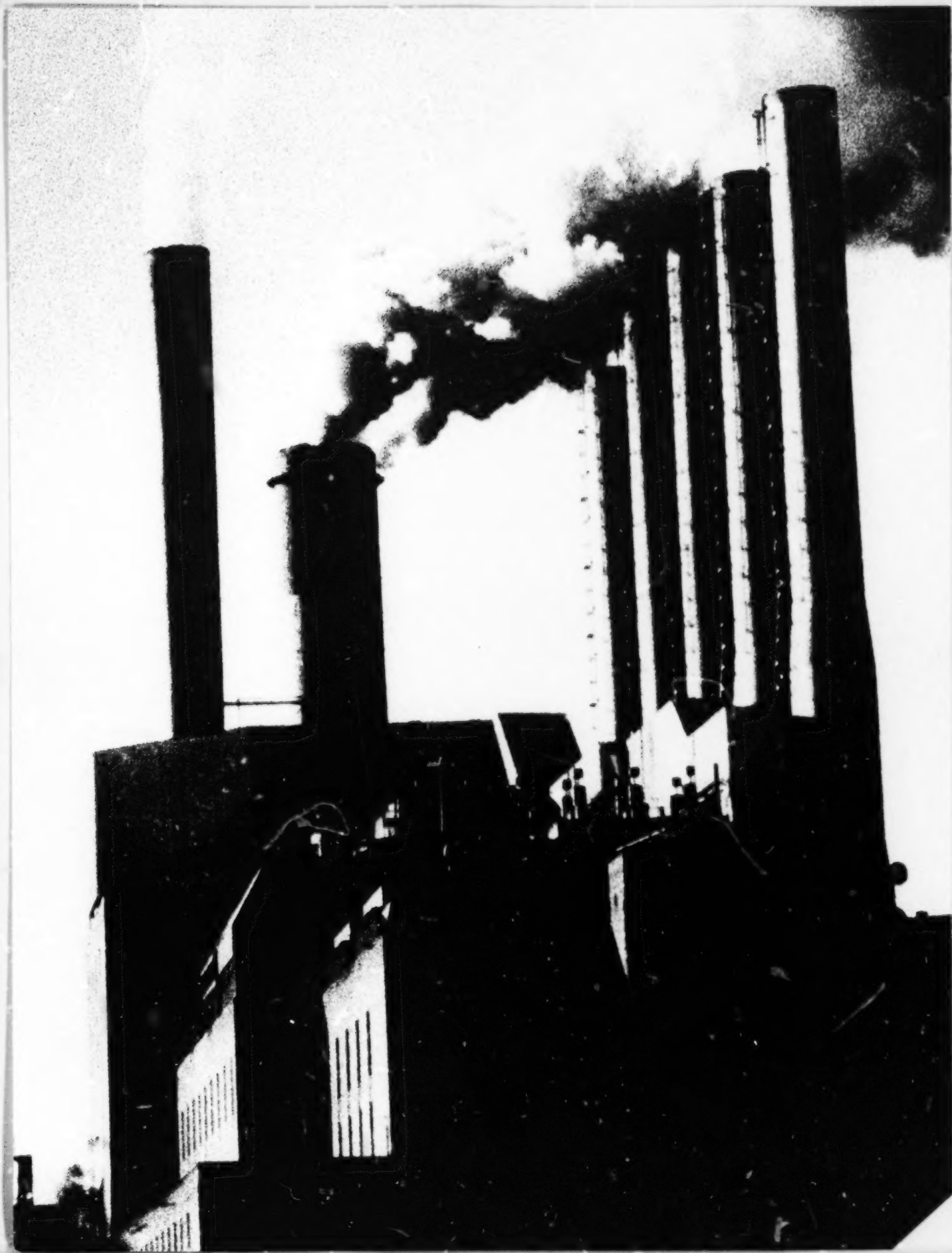
Revised NSPS, promulgated in June, 1979, require a specific percentage of sulfur reduction and a maximum ceiling amount of sulfur per million BTUs. This means that some form of sulfur oxide control technology will be required for all types of coal, regardless of sulfur content.

To meet the present air quality standards, some form of SO_2 emission control technology may be necessary on an estimated 25 percent of the coal-fired plants in the U.S. In the future, all new plants must install sulfur oxide pollution control systems.

What emission control systems are there currently available? What is the state of development of alternative control technologies?

sources of society generated sulfur pollution





emission control technologies

Today, flue gas desulfurization (FGD) technology is playing a critical role in sulfur oxide pollution control. It is the only control technology commercially available that can be used to reduce sulfur oxide emissions to comply with the Clean Air Act. Being an "add-on" or post-combustion type of system, it can be retrofitted with minimum modification to existing boiler combustors. Over the next five years or so, the only other available options that can provide some degree of sulfur oxide control are the use of low-sulfur coal and physical coal cleaning.

In the past, the utilities and other industrial sources relied on several approaches to reduce SO₂ emissions. They used low-sulfur coal when it was readily available and economically advantageous to do so. Converting facilities to burn oil and gas — both cleaner burning fuels — was also a feasible approach before the oil crisis of 1974. In other cases, modernization of "dirty" combustion equipment provided sufficient improvement to meet emission standards. Such approaches to SO₂ emission reduction, however, have gone about as far as possible; further improvements in SO₂ reduction are not expected without the application of control technology.

low-sulfur coal

While naturally occurring low-sulfur coal is the most straightforward control option, projected production capacity for such coal is limited. It has been estimated that production of low-sulfur coal will satisfy less than 44 percent of the anticipated demand for this type of coal in 1980. Also, most of the low-sulfur coal reserves are in the west. Using the western low-sulfur coal to meet mid-western and eastern requirements would involve substantial transportation costs. Because of these additional costs, it is economically feasible to use local high-sulfur coal and clean up the resulting pollution by applying SO₂ control technologies. Furthermore, recent tightening of the emission standards eliminates the low-sulfur coal option for new sources.

physical coal cleaning

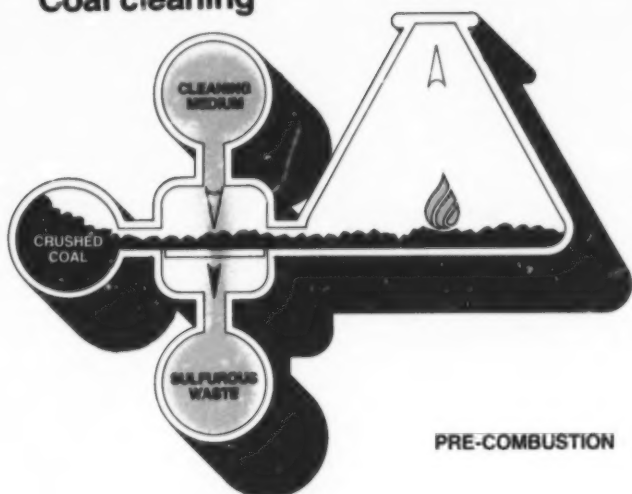
Another option for reducing SO₂ emissions is physical coal cleaning, which has been used for many years. In the past, its principal purpose was to reduce ash-forming impurities. Today, this technology is commercially available, relatively simple, and low in both capital and annual costs. Up to 80 percent of the inorganic sulfur can be removed by physical removal techniques. Its use is limited, however, to removing inorganic sulfur (pyritic sulfur) in coal. Sulfur also exists in coal in the form of organic sulfur, which is chemically bound to the coal and cannot be removed by physical means. The extent to which inorganic sulfur can be removed economically is also limited, because it depends on the size and distribution of this form of sulfur in a particular coal. It has been estimated that less than 14 percent of U. S. coal reserves is of the type that can be physically cleaned to meet the present NSPS standards.

Thus, although both of these options — low-sulfur coal and physical coal cleaning — are currently available, their application is limited.

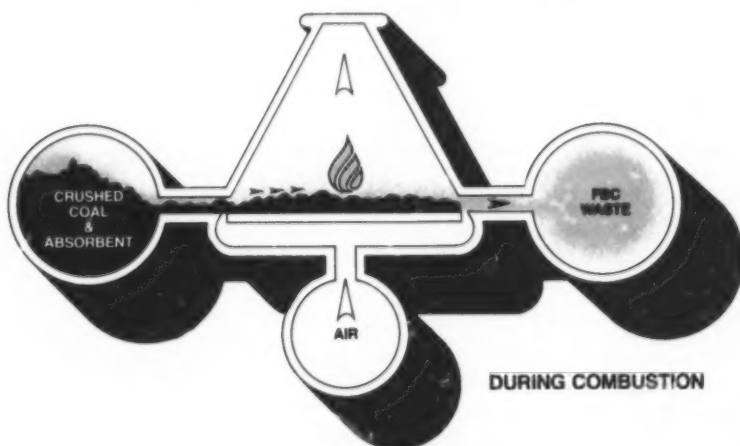
flue gas desulfurization

Flue gas desulfurization technology is the SO₂ emission control approach that is most common today. Although there is a great deal of activity and interest in these FGD control systems, commonly called "stack gas scrubbers," they are not new. The first commercial use of FGD to control sulfur oxide pollution from a power plant was in the United Kingdom in the early 1930s. Flue gases were washed with alkaline water from the Thames River at the Battersea A power plant of the London Power Company. The spent alkaline water was discharged back into the Thames after settling and oxidation. This FGD system operated successfully for over 40 years, at up to 95 percent SO₂ removal efficiency, until the power plant closed in 1975.

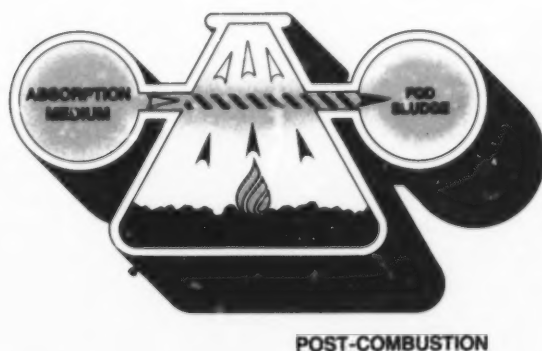
Coal cleaning



Fluidized Bed Combustion (FBC)



Flue Gas Desulfurization (FGD)



During the 1950s and '60s, the new FGD processes were being developed and pilot tested. During the '50s, the Tennessee Valley Authority (TVA) investigated both wet and dry lime/limestone scrubbing systems and dilute acid processes. At the same time the Germans developed the first major carbon absorption processes. During the '60s, magnesium oxide, copper oxide, and sulfite scrubbing processes were investigated.

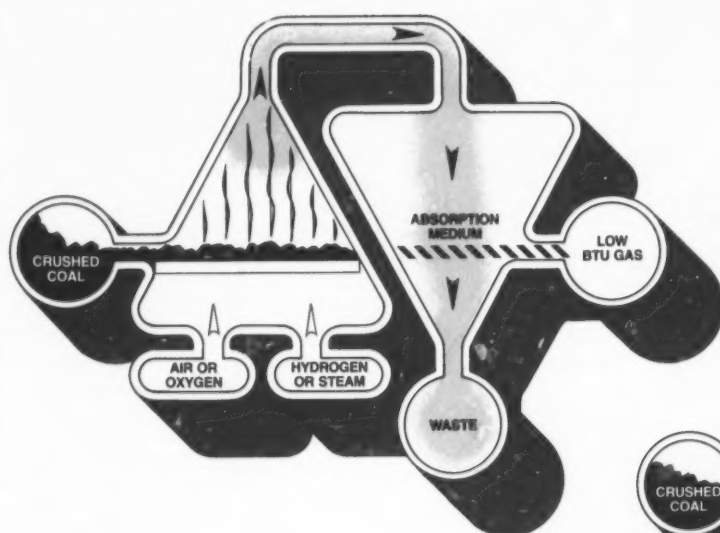
Over the past 10 years, the EPA and TVA have sponsored extensive research, development, and demonstration programs designed to develop FGD as a practical SO_2 control approach. As a result, several types of FGD systems have been developed and applied to operating power plants. These systems have demonstrated, over several years of operation, increasing reliability and performance in removing up to 90 percent of the SO_2 emissions. Recent pilot-plant experience indicates that new FGD systems can be expected to exceed 95 percent removal.

The number of FGD systems installed annually in the United States has steadily increased since 1968. As of early 1978, there were 29 units in operation, with an additional 51 units in design or under construction. Nearly 25,000 megawatts (MW) of FGD capacity were installed or under construction on both new and existing utility boilers; approximately 30,000 MW of FGD capacity were in the planning stage. This total utility commitment of 55,000 MW FGD capacity represents over 25 percent of the current total U.S. coal-fired capacity of 200,000 MW.

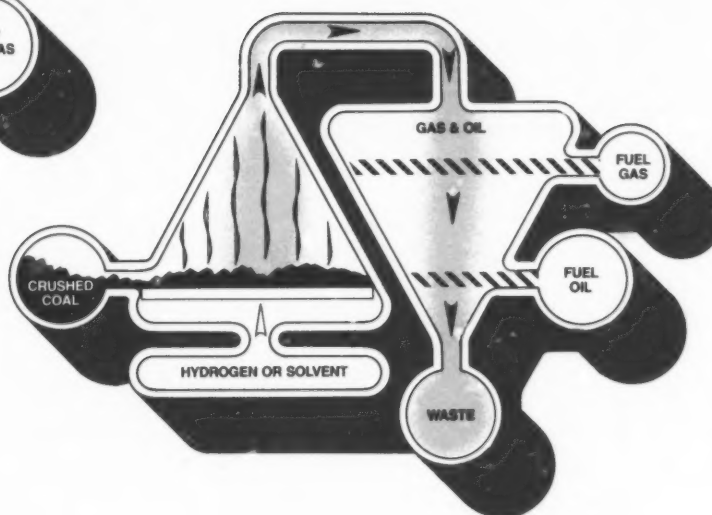
FGD systems can be classified into two general types:

- **non-regenerable or throwaway systems**, in which the sulfur material generated through scrubbing or absorption is disposed of as a waste product, and
- **regenerable or recovery systems**, in which sulfur materials, such as elemental sulfur, liquid SO_2 , and sulfuric acid, are marketed as saleable products.

Gasification



Liquefaction



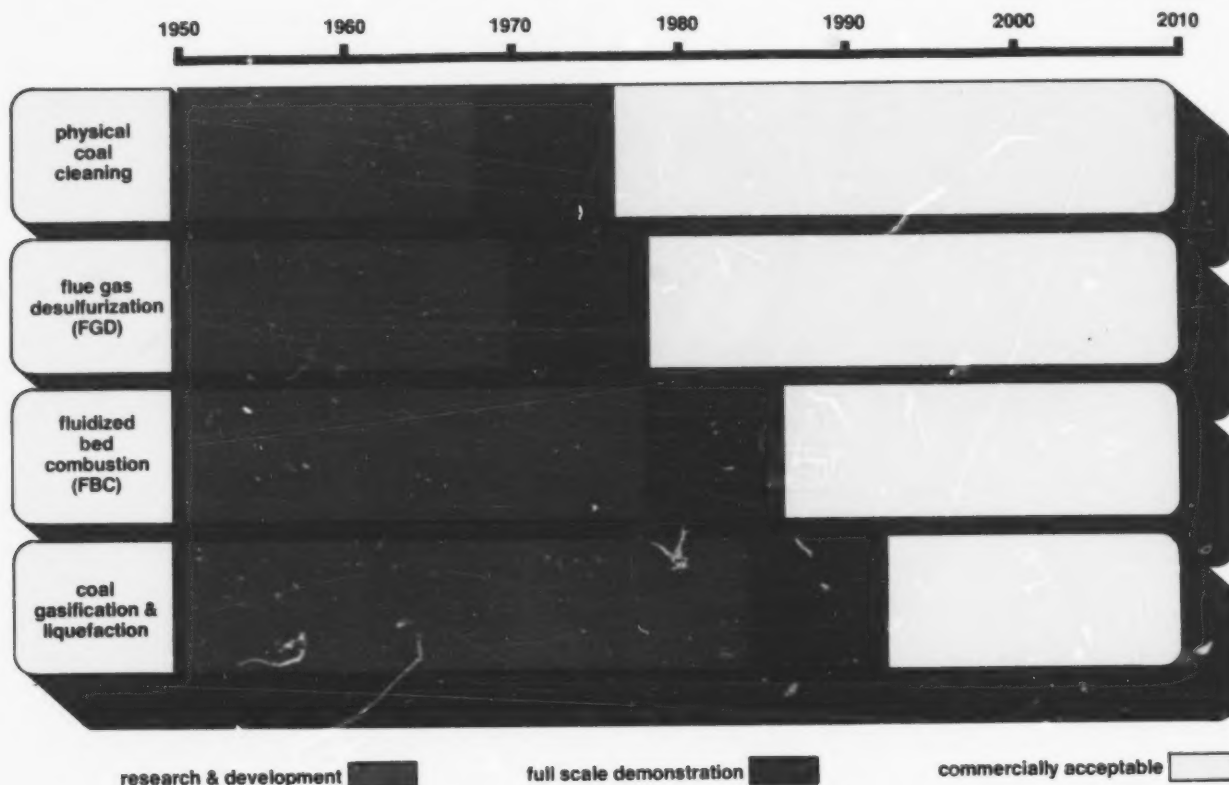
About 90 percent of FGD systems currently operational, under construction, or in planning are lime or limestone scrubbers of the throwaway type. Although over 50 FGD processes have been tested at bench scale or larger, the number of commercially significant processes is considerably smaller. The following throwaway FGD systems are considered the most important for near-term (through 1985) SO_2 control:

- **direct lime scrubbing and direct limestone scrubbing** — the lime and limestone scrubbing systems are commercially available technologies. These systems use a slurry of lime or limestone to absorb SO_2 from combustion gases, thereby producing a waste product in the form of a slurry or sludge.
- **double alkali scrubbing** — the double alkali scrubbing is a second generation technology. Double alkali systems use scrubbing solutions of soluble alkali salts, e.g., sodium, for SO_2 removal. The spent scrubbing liquor is then reacted with lime outside the scrubber system thereby forming a slurry which, after drying, produces a caked waste product.

Of the types of recovery FGD systems, the following are considered most important for the same near-term period:

- **magnesium oxide scrubbing** — magnesium oxide (magnesia) is used to remove the SO_2 , forming magnesium sulfite. Solids of magnesium sulfite are separated by centrifugation and dried. The magnesium sulfite is then calcined (oxidized by heating) to regenerate magnesium oxide which is reused, and the SO_2 gas is converted into sulfuric acid.
- **Wellman-Lord process** — sodium sulfite is used as the absorbent to obtain sodium bisulfite, which is heated to regenerate sodium sulfite and SO_2 in a concentrated form. The recovered SO_2 is used to by-produce either sulfuric acid or elemental sulfur.
- **citrate, carbon adsorption and copper oxide adsorption** are some other potentially important systems which have operated at or near commercial scale.

projected availability of alternate control technologies



fluidized bed combustion

An emerging technology that shows significant potential for a clean-burning process is fluidized bed combustion (FBC). Fluidized bed combustion involves the combustion of pulverized coal in a bed of granular limestone or dolomite. The combustion takes place in a closed vessel containing a porous plate that supports a bed of pulverized coal and limestone/dolomite sorbent. Air is passed through the plate, "fluidizing" the bed of coal and sorbent. As the coal burns, the SO_2 is absorbed by reaction with the limestone. Coal and sorbent are fed continuously to the bed, while spent sorbent and ash are continually removed.

There are two types of FBC processes: atmospheric fluidized bed combustion (AFBC) and pressurized fluidized bed combustion (PFBC). The AFBC process operates with the combustion chamber at close to atmospheric pressure. Pressurized fluidized-bed combustion operates at pressures from 6 to 16 times atmospheric pressure.

In the AFBC system, steam is produced inside tubes that are built into the combustion chamber. Electricity is generated in a conventional steam turbine. In the PFBC system, steam is produced in similar tubes, but more importantly, the hot gases from the combustion chamber are used to drive a gas turbine generator. Additional energy efficiency can be obtained by using the waste turbine heat to produce steam.

For several years, a considerable effort has been expended in the development of FBC, with DOE and EPA supporting the experimental work in both the U. S. and England. The culmination of the effort has been the construction of a 30-MW AFBC plant at Rivesville, West Virginia. This plant is currently the largest FBC unit in the world. Other small industrial AFBC units are planned, but none is expected to be operating until 1979. On a larger scale, TVA has preliminary designs for a AFBC steam generator under development and is studying the construction of a 200-MW demonstration unit.

The AFBC systems are in a more advanced stage of development than PFBC systems. This is principally because the pressurized systems require the development of high pressure gas cleaning technology. Both systems require a considerable flow of sorbent material through the combustion chamber. In the AFBC system, the spent sorbent is discarded producing a significant solid waste disposal problem.

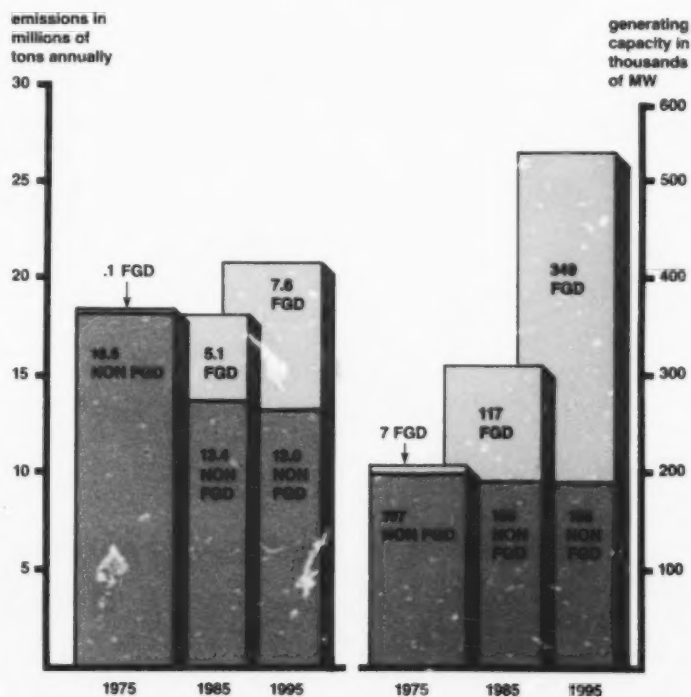
The amount of sorbent required and the associated spent sorbent disposal problems can be greatly minimized by employing a regeneration process.

Research is in progress on the PFBC system to regenerate the spent sorbent. Added benefits from this process may be the production of by-product chemicals such as elemental sulfur and sulfuric acid.

This during-combustion control technology may eventually surpass other conventional post-combustion control processes in its potential for air pollution control and economy. It is a way of burning coal (as well as other fuels) in a clean and economic manner. Because of the higher heat transfer characteristics inherent in the process, the combustors are more compact than conventional coal combustors and the system more energy efficient. While the combustion temperature is sufficiently high for efficient combustion, it is low enough to produce a decrease in nitrous oxide emissions and allows the formation of calcium sulfate as a by-product of burning sulfur-bearing fuels.

The fluidized-bed combustion system is viewed as a potentially energy-efficient technology that could have some useful economic and environmental advantages. Preliminary data from Rivesville indicate that the SO₂ reduction is in the range of 85 to 89 percent with the limestone feed that is presently being used there.

control of sulfur emissions in U. S.



TECHNOLOGY	DESCRIPTION	CURRENT STATUS	ADVANTAGES
PHYSICAL COAL CLEANING	removes inorganic sulfur by using difference in specific gravity of sulfur & coal	- commercially used - future limited as emission standards become more stringent	- can be used in conjunction w/ FGD to reduce costs - inexpensive process - does not require boiler modifications (normally)
FLUE GAS DESULFURIZATION	remove SO₂ from combustion gases after burning through absorption in an alkaline solution	- commercially used - offers most efficient and economical method of SO₂ control now available on a widespread basis	- can be retrofitted to existing boilers - efficient
FLUIDIZED BED COMBUSTION	- combustion of pulverized coal in a bed of limestone or dolomite - fluidized by air, SO₂ absorbed by absorbent	- emerging technology in pilot plant testing - commercial availability for atmospheric FBC in mid-1980's; in early 1990's for pressurized FBC	- SO₂ removal: 80-90% - lower combustor capital costs - wide fuel flexibility - lower operating temperatures
LIQUEFACTION	reaction with hydrogen, heat & pressure, in presence of catalysts or chemical solvents to produce liquid fuels	4 processes in pilot stage: —direct catalytic hydrogenation —solvent extraction —pyrolysis —liquid hydrocarbon synthesis - commercialization: 1990's	- wide variety of coals - produces clean burning fuels - SO₂ removal: > 95%
GASIFICATION	reaction with steam or hydrogen & air/oxygen at high temperature to produce high or low BTU gas	- low BTU commercialization: mid 1980's - current low BTU demonstration (small scale industrial) - high BTU commercialization: 1990	- can be used in conventional gas fired power plants - SO₂ removal: > 95%

other emerging control technologies

Other pre-combustion coal technologies under development that would reduce SO₂ emissions, as well as provide additional domestic supplies of rapidly depleting fuel resources, include coal gasification and coal liquefaction.

Low BTU gasification is currently in the demonstration phase of development and is expected to make a commercial impact in the mid-1980's. High BTU gasification and liquefaction are currently in the pilot plant stage of development and are expected to be commercialized in the post 1990 period.

These technologies will produce relatively clean burning fuels to replace natural gas for residential heating and fuels for boiler and transportation

DISADVANTAGES**ECONOMIC FEASIBILITY****WASTE PRODUCT**

only 14% of U. S. coals can be cleaned enough to meet NSPS standards

may require large electrostatic precipitator

- relatively inexpensive but limited in application

- large quantities of high sulfur refuse/ash

generates large quantities of sulfur laden sludge

- provides an effective and efficient means of meeting NSPS emission standards without modifying or replacing existing boilers

- sludge

generates large quantities of spent absorbent
larger precipitators required

- appears to have economic advantage over FGD operating & capital costs

- dry spent sorbent

unidentified pollution problems
potential for toxic by-products
high particulate control needed

- high overall development costs

same as liquefaction

- same as liquefaction

applications. At present, however, their environmental impacts have not been adequately determined. The Environmental Protection Agency has initiated a comprehensive environmental assessment program to develop and evaluate pollution control technology associated with these processes in an effort to reduce their effluents and emissions.

All of these control technologies reduce emissions of air pollutants; however, they generate other pollutants—solid and liquid byproducts. Thus, there are two environmental problems associated with sulfur oxide pollution: first, the SO_2 control problem; and second, the waste management problem resulting from the application of SO_2 controls.

What is the size and scope of this waste management problem? What are our options for disposal and/or utilization of SO_2 control wastes?



waste management

The management of solid wastes is a major problem for electric power producers and industrial boiler operators using throwaway FGD control systems. Because the waste must be disposed of within the constraints of land and water quality regulations, EPA is funding an extensive research and development program to evaluate, develop, and demonstrate environmentally acceptable methods for disposal and treatment of FGD waste. Studies are also being sponsored on the economics of current and conceptual disposal technologies. Extensive field investigations are being conducted on a process (forced oxidation) for converting FGD waste into gypsum, the basic ingredient of plaster. The Tennessee Valley Authority (TVA) also has been active for several years in developing and evaluating FGD scrubber systems and FGD waste treatment and disposal methods. Over the next five years the Electric Power Research Institute (EPRI) will be funding an extensive research and development program related to FGD waste treatment and disposal.

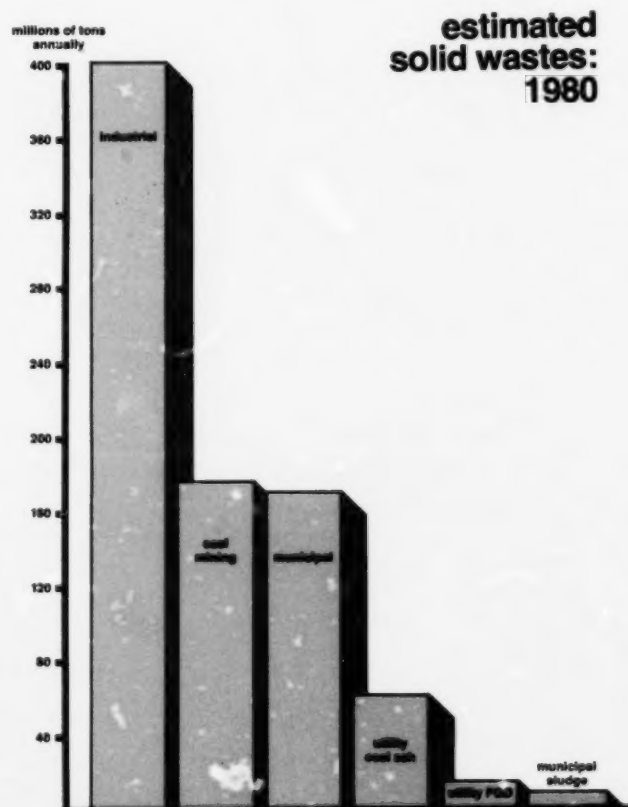
scope

Waste management associated with emission control systems is of environmental concern because of the large amount of solids and liquids generated by those systems. For the FGD process, which will be the primary emission control technology in use for the near term, the total amount of FGD waste produced in a typical 1,000 MW plant, burning coal with a 3.5 percent sulfur content, is about 225,000 tons annually. This is comparable, on a dry basis, to the amount of coal ash produced. (When burning low-sulfur, western coal, the amount of FGD waste produced is only 30 to 40 percent of the ash generated.)

To place FGD scrubber waste in perspective, the amounts of FGD wastes generated annually can be compared with other kinds of utility, industrial, mining, and municipal wastes that our society has been dealing with for many years. For example, during 1980, the amount of coal ash generated by utilities alone will be nearly six times the amount of FGD waste generated from utility applications. The amount of solid waste from mining coal is about fifteen times greater than FGD waste and

about the same as the amount of municipal refuse generated annually. Industrial wastes are almost forty times the amount of FGD waste. Municipal sewage sludge projected for 1980 will be about half the amount of FGD sludge generated from utilities.

Many of these types of solid wastes contain potentially hazardous constituents, for which techniques have been developed to reduce their environmental, public safety and health impacts. These techniques include disposition by ponding and landfill. Although some problems associated with non-FGD wastes have not been completely resolved, work is continuing to improve treatment and disposal methods. It is expected that continuing research and development will lead to improved methods for managing and disposing of SO₂ control technology wastes, as well.



land use

With the increasing application of emission control systems will come additional requirements for land for disposal of generated wastes. For example, a typical 1,000-MW utility plant will require 400 to 700 acres for disposal of ash and FGD waste over a lifetime of 30 years depending upon the type of coal and the regional locations. This acreage includes only the excavated area (landfill or impoundment). The actual disposal area may be larger, since land would be required for access roads, truck parking and unloading areas, and buffer zones. It is anticipated that public concern about buffer zones to lessen the adverse aesthetic impacts of disposal areas will further increase land requirements.

Preliminary estimates of maximum national land requirements for the waste disposal area are 18,000 acres by 1985 and 63,000 acres by the year 2000. These estimates are the upper limits for the disposal area if all FGD waste is disposed of on land, i.e., with no product utilization or other disposal method. Actual land taken for this use—which would include access roads and buffer zones—would be higher.

disposal regulations

The disposal of FGD waste is subject to regulations at both the Federal and state levels. At present, FGD waste is disposed of exclusively on land.

Four major issues impacting land disposal are:

- **Waste stability/consolidation**
- **Groundwater contamination**
- **Surface water contamination**
- **Fugitive emissions**

The issues are regulated under a number of Federal legislative acts. One of the most significant of these is the Resource Conservation and Recovery Act of 1976, which regulates the disposal of all types of wastes in mines, landfills, and impoundments. It requires the development of criteria that classify disposal areas as either open dumps or sanitary landfills. These criteria address all forms of land disposal, including impoundments, land spreading, and surface mine disposal. After the criteria are issued, the states must develop plans which require that existing open dumps be upgraded or closed. Future land disposal operations will be required to meet the criteria established for sanitary landfills. The criteria are expected to prohibit any contamination of the groundwater that would result in requiring additional purification steps before using.

disposal alternatives

Ponding and landfill are the two primary methods currently in use for disposing of FGD sludge. In addition to these, EPA, through its Office of Water and Waste Management, is developing methods to improve the existing disposal technology and is also examining alternative disposal options. Two of these alternatives are mine disposal and ocean disposal.

Ponding of Untreated Sludge—At present, FGD scrubber waste is primarily disposed of without additional physical or chemical treatment, although the waste is sometimes thickened prior to discharge. Historically, the disposal method most frequently used by utilities has been ponding. In most ponding operations, the slurried solids are pumped directly from the scrubber or from the bottom outlet of a thickener to a disposal pond usually located within a mile of the power plant. Ponded waste settles to a semi-solid toothpaste-like material, and excess water is returned to the scrubber. Some utilities do not line the disposal pond, while others install a clay lining.

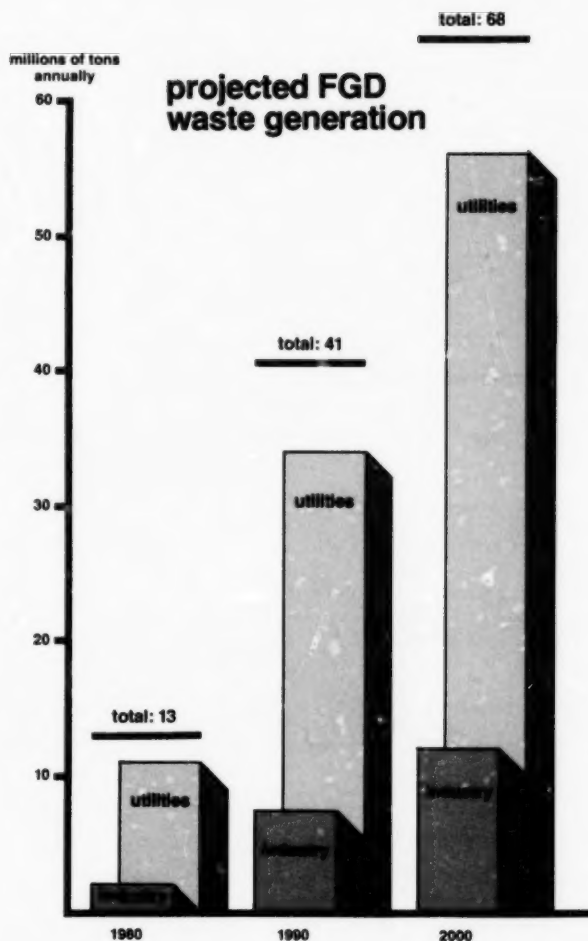
Two environmental issues arise from the ponding of FGD waste:

- **Water pollution potential** of soluble materials in the waste
- **Land-degradation potential** of nonsettling or physically unstable waste.

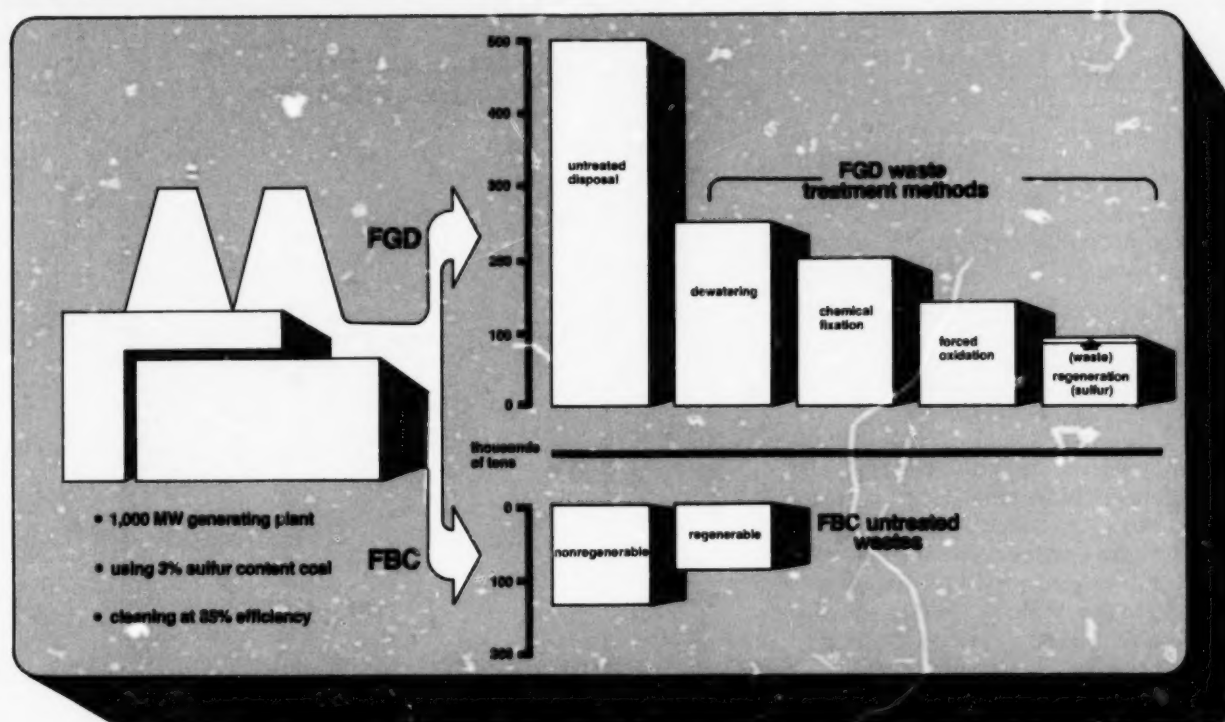
In all ponding operations, local surface and groundwater must be monitored for possible contamination by leachate from the disposal pond. Because of the physical properties of untreated FGD waste, the settled waste is not structurally stable. Even after extended settling, the waste possesses thixotropic properties, that is, if physically disturbed, it becomes fluid. This creates handling problems during transport and landfill disposal, and impedes future reclamation of the ponds. In addition, if the pond is not reclaimed and an appreciable level of water is permitted to remain indefinitely on top of the waste, soluble constituents can be forced into the groundwater.

With regard to ponding of untreated sludge, it is EPA's position that permanent land disposal of raw (unfixed) FGD waste is environmentally unsound because it indefinitely degrades large quantities of land (Federal Register, Volume 40, No. 176, September 1, 1975). By fixing or chemically treating FGD waste, it sets up into hard, clay-like form that permits it to be disposed of in a more environmentally acceptable manner. Several such treatment methods have been developed and are commercially available.

Landfill Disposal—Where ponding has been impractical, landfilling has been used for many years by utilities as a means for disposing of coal ash. FGD waste has also been disposed of as landfill in some areas, in order to avoid the land deterioration and water pollution associated with ponding.



comparative waste output: FGD/FBC



For landfill disposal, the FGD sludge must be dewatered or chemically treated before being hauled to the disposal site. In some cases, untreated slurries are pumped to the disposal site for dewatering or treatment. The dewatered wastes are then placed and compacted. Although sanitary landfill procedures (daily covering) are not necessary, the soil may be periodically layered to minimize exposure to rainfall. This practice reduces leaching and possible reslurrying in the case of untreated wastes. FGD sludge must have enough physical stability to be handled by earthmoving equipment for landfill disposal. This means the material must be dewatered to at least 50 percent solids and possibly to as high as 65 to 70 percent solids by mechanical, thermal, chemical or a combination of these methods.

Mine Disposal — Disposal of FGD waste in coal mines has interested utility engineers and EPA scientists for many years. The transportation system for moving the waste from the plant to the mines already exists in the form of the railroads used for bringing coal to the plant. In addition,

many plants have inadequate land area for on-site disposal. This potential has led EPA to support several studies to examine the potential of this disposal option.

In one study, an initial technical/environmental screening identified four general categories of mines as the most promising candidates for FGD sludge disposal: (1) active surface coal mines, (2) active underground coal mines, (3) inactive or mined-out portions of lead/zinc mines, and (4) inactive or mined-out portions of active underground limestone mines.

Midwestern surface mines appear to be the most promising area for surface mine disposal. The waste would have to be dewatered to 65 to 70 percent solids so that it could be dumped into a mined-out strip, adjacent to one being mined, and then covered over. Both midwestern and western surface mines were considered to be much more promising than eastern surface contour mines, because of the latter's low capacity for FGD waste and the greater difficulty in placing the waste in the contour mines. However, a disadvantage of the western surface mines is their greater potential for groundwater contamination.

Disposal of FGD waste in surface mines is currently planned by several utilities. An

evaluation of their experience will enable the suitability of this disposal option to be fully determined.

Finally, the study concluded that for underground mine disposal, the placement of either treated or untreated FGD waste would tend to neutralize and reduce acid mine drainage. This would result in improving both groundwater and nearby stream water quality. In addition to this benefit, disposal of chemically treated FGD wastes could minimize long-term mine subsidence by providing lateral pillar and roof support. Untreated wastes would not be expected to provide sufficient strength for subsidence control unless substantial settling of the waste solids occurred after placement.

Contamination of groundwater in the mine would most likely occur if untreated FGD waste were used. Contamination of public supply aquifers is not expected, although the water quality of nearby streams would be affected.

Ocean Disposal—Ocean disposal of wastes has occurred for many years. However, in view of the increasing awareness of the adverse effects of much of this activity, recent efforts have been undertaken to reverse the degradation of the ocean environment. The Marine Protection Research and Sanctuaries Act of 1972, the major Federal legislation in this area, states, "The Congress declares that it is the policy of the United States to regulate the dumping of all types of materials into ocean waters and to prevent or strictly limit the dumping into ocean waters of any material that would adversely affect human health, welfare, or amenities, or the marine environment, ecological systems, or economic potentialities."

Based on these criteria, studies have been undertaken to determine if ocean disposal is an environmentally acceptable alternative. Several preliminary conclusions were drawn:

- Until more definitive data are available, it would appear that disposal of untreated FGD waste on the Continental Shelf or in the deep ocean is not advisable.
- It appears that all soil-like FGD wastes — sulfite or sulfate, treated or untreated —

should not be disposed via quick dumping surface craft or pipeline (outfall) on the Continental Shelf.

- The following option (using surface craft) may have potential, but requires further study:
 - Concentrated disposal of treated, brick-like waste on the Continental Shelf. In this regard, a pilot demonstration of the concept of artificial reefs of this material is being sponsored by EPA, DOE, EPRI, Power Authority of the State of New York, and the New York State Energy Research & Development Authority.

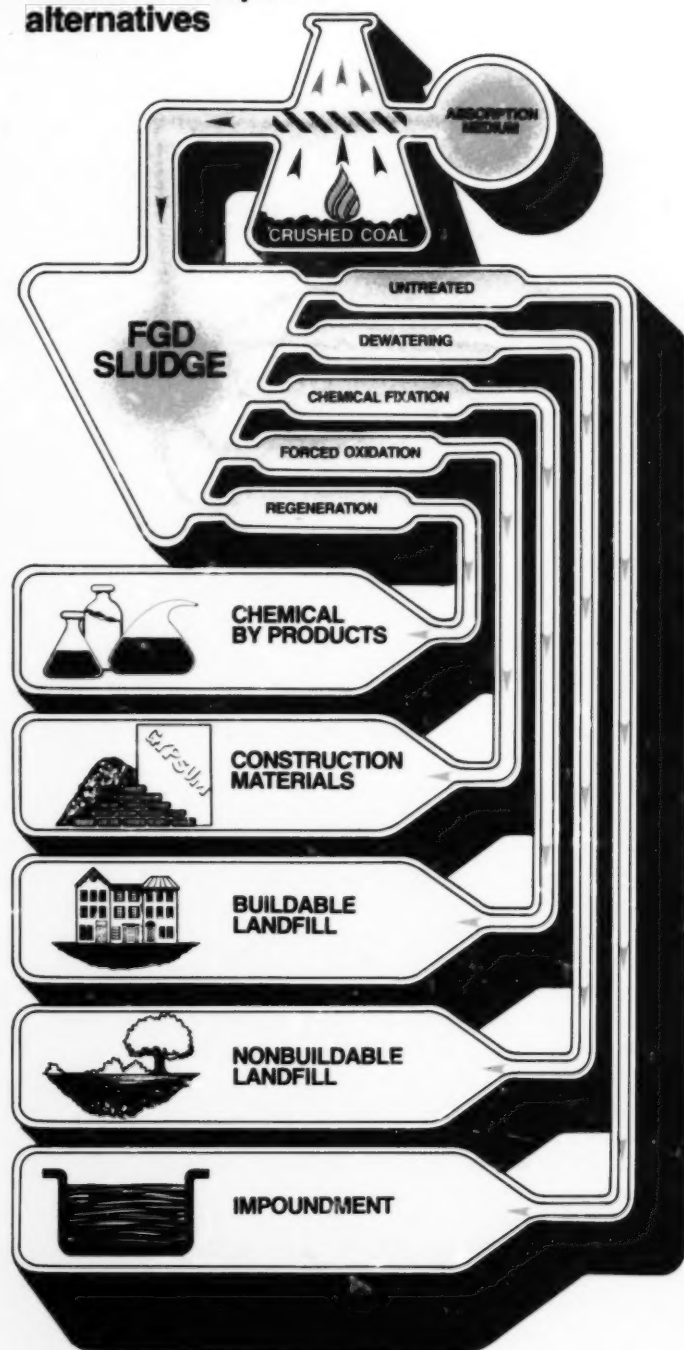
treatment alternatives

Forced Oxidation—Under EPA's FGD and Water and Waste Management Programs, forced oxidation technology is being investigated as an alternative treatment option. The process consists of forcing air into the slurry of calcium sulfite waste to oxidize it into calcium sulfate, which is gypsum. The gypsum can then be easily dewatered to greater than 80 percent solids.

Beginning in 1976, studies conducted by EPA with the 0.1 MW pilot plant at the Industrial Environmental Research Laboratory located at Research Triangle Park, North Carolina (IERL-RTP), have shown that calcium sulfate can be readily oxidized to gypsum by simple air/slurry contact in a hold tank to the scrubber recirculation loop.

Based on the findings at the IERL-RTP pilot plant, a program was initiated at the Shawnee Test Facility located at the TVA Shawnee Steam Plant near Paducah, Kentucky, to develop operational procedures for forced oxidation. Forced oxidation testing was initiated in January 1977 on the 10 MW EPA prototype scrubbers and has continued as a major part of the Shawnee Advanced Test Program. These tests are designed to determine the optimum operational parameters and long-term reliability of the process equipment. Runs of a month or more in duration, using lime/limestone scrubbing with forced oxidation, have been

FGD waste treatment/disposal alternatives



successfully demonstrated on prototype process equipment. Scale-up of these results to commercial scrubbing equipment appears quite feasible.

Leachate from land disposed gypsum will be similar to that from untreated FGD waste and therefore should be prevented from entering water supplies. Because gypsum tends to form a protective surface scale capable of shedding rainwater, tests are currently being conducted at the Shawnee test site to determine if land disposal of gypsum is feasible without the use of ground liners or impoundment dikes. Limited results have shown that gypsum sludges crack badly under freeze-thaw conditions, thereby allowing rainwater to enter into the material. Also, gypsum sludge has been found to slump in its freshly deposited condition when exposed to rainfall. This results in runoff containing potentially high concentrations of dissolved solids from the sludge. These preliminary results indicate that considerable site maintenance may be required on an operational scale to reconfigure the disposal pile after weathering (freeze-thaw and erosion) and to control the runoff. Tests are continuing to determine what controls should be exercised at the site during and after disposal.

Commercial Fixation—Several utilities presently stabilize or "fix" the sludge through chemical treatment. These fixation processes result in a solidification or hardening of the sludge to a clay-like material. This material can then be left in an impoundment or hauled to a landfill.

One process developed by Dravo Lime Company involves the addition of Calcilox®, a cement-like product derived from basic, glassy blast furnace slag, to FGD sludges. Dravo's "full impoundment" disposal process produces a stronger, more stable, less permeable material than simple ponding. Principal advantages of the stabilized product are: the volume of leachate is reduced and the leachate quality is improved, the final site is more suitable for other development, and there is less danger from dam or dike failures.

Another process, developed by IU Conversion Systems, Inc. (IUCS), involves vacuum-filter dewatering of FGD waste followed by the addition

of lime, dry fly ash, and other additives to produce a dry product called Poz-O-Tec which can be landfilled. When Poz-O-Tec is properly placed and compacted in a landfill, it has a lower permeability, higher density, and greater strength than untreated wastes. Leachate concerns are reduced, and possibilities for ultimate land reclamation and usage are increased. The Poz-O-Tec process generates a dry material, allowing for greater flexibility in the utilization of disposal areas and increasing the possibility for by-product utilization in applications such as roadway pavement.

The Dravo and IUCS processes have been in operation at several full-scale plants for nearly two years. Additional data are now being collected to determine their long-term operational characteristics.

Fly Ash Blending—One of the easiest ways to dewater FGD wastes is by adding dry solids such as fly ash. Without fly ash blending, a maximum of only 50 to 60 percent solids can be obtained through gravity settling followed by vacuum filtration. However, if an equivalent amount of dry fly ash is added to a 55 percent solids material, an increase to about 70 percent solids is obtained. Some power plants have developed their own blending formulas such as mixing sludge with fly ash and lime (similar to the IUCS process) or adding dry fly ash to sludge prior to landfilling.

Treatment Overview—Overall, it appears that chemical treatment or other stabilization processes are desirable to improve the FGD waste disposal operation. Additional cost for these processes are

environmental concerns of waste disposal alternatives

waste disposal/ treatment alternatives	ponding	mine disposal	ocean disposal	landfill	dewatering	chemical fixation	forced oxidation	regeneration
waste stability	●			●	●			
groundwater contamination	●	●		●	●	●	●	
surface water contamination	●	●					●	
fugitive emissions				●				●
land degradation	●				●		●	
damage to marine life			●					

minimal, and they greatly enhance the opportunities for long-term use of the affected site.

commercial utilization

As an alternative to disposal, FGD waste, after treatment, can be utilized as a raw material component in the production of various commercial products. In addition to the utilization of recovered gypsum, technology has been developed to use chemically treated FGD waste in products and applications such as mineral wool, bricks, concrete products, soil amendment, mineral recovery, road base materials, parking lot materials, and aerated concrete. However, in spite of efforts to promote some of these products, little or no commercial utilization is occurring in the United States at present. This situation could change if these raw materials become more economically competitive with their presently available counterparts.

Several recent EPA and utility-funded studies have been conducted on the potential for by-product recovery from FGD waste. In one study, gypsum was used in the manufacture of standard wallboard. The study identified some potential problems associated with this utilization of FGD waste. For example, it was found that the gypsum containing fly ash can cause wallboard bonding problems, due to the presence of iron and various salts in the fly ash. This problem, however, is characteristic of only certain types of coal. There are coals that burn with a fly ash that does not contain sufficient quantities of contaminants to cause such problems. Fly ash and other impurities

also were found to cause tinting of the wallboard. However, this may not preclude sale of such wallboard in some markets.

EPA has also funded two TVA computer model studies on the potential market for FGD by-products; one on the feasibility of gypsum production and marketing for use in wallboard and cement, and the other on the potential for production and marketing of by-product sulfuric acid in the U.S. The pertinent conclusions from these studies are:

- Cement plants offer the greatest market outlet for by-product gypsum.
- The wallboard industry, as presently structured, would provide an extremely limited market. Use of FGD gypsum in wallboard could be feasible, however, if new wallboard plants were built nearby to power plants, so that savings could be realized in transportation costs for gypsum.
- At the present price level of elemental sulfur, the market for by-product sulfuric acid from power plants would be saturated at approximately 15 percent of the total market.

International Experience — In contrast to the U.S., both Japan and the Federal Republic of Germany have considerable experience with nonregenerable FGD and have emphasized the recovery of usable by-products from the FGD waste.

In the Federal Republic of Germany, FGD processes and by-product utilization were under intensive study, as of late 1977, although there were no large-scale operational applications of FGD. Because limited space is available for disposing of FGD waste, emphasis is being placed on the development of FGD systems that produce marketable by-products. One system under development will produce high grade gypsum for use in the construction and mining industries and in the manufacture of cement.

economics

FGD WASTE TREATMENT/DISPOSAL ALTERNATIVES		ESTIMATED LEVEL OF INVESTMENT REQUIRED FOR FGD CLEANING & DISPOSAL SYSTEMS				
		capital investment *\$MM	annual operating* costs \$MM	cost per ton of dry solids \$	cost per KWH in mills	potential for income producing by-products
UNTREATED DISPOSAL	ponding	36.5	6.7	5.55	.064	none
	landfill	17.2	7.7	6.38	.074	none
	mine			3.50		none
TREATMENT SYSTEMS	chemical fixation	21.0	14.3		1.36	• buldable landfill
	forced oxidation	15.0	6.0		.85	• gypsaum

* estimates based on 500 MW generating plant and 3.5% sulfur coal

Proceedings: Symposium on FGD, Hollywood, Florida November, 1977.

In Japan, about 1,000 FGD plants, having a combined capacity of about 31,000 MW, were operational at the beginning of 1978.

Approximately half of the total capacity represents utility boiler applications (primarily oil fired), while the remainder includes industrial boilers, sintering plants, smelters, and sulfuric acid plants.

Because natural gypsum is not available in Japan, forced oxidation in FGD scrubbers has been employed extensively to produce high-quality gypsum raw material for the cement and wallboard industries. Gypsum is by-produced by plants comprising about 65 percent of the total Japanese FGD capacity. The remaining FGD plants utilize waste to by-produce sulfuric acid, elemental sulfur, ammonium sulfate, and sodium sulfite or sulfate.

Japanese FGD practice has been the subject of intensive study by U.S. government agencies. An interagency task force recently completed a study on the status of FGD in Japan.

economics

The economics of waste treatment, disposal, and utilization should be considered in selecting SO₂ control technologies for utilities and industrial facilities. This is because the costs associated with waste management are an important element in the total costs of installing and operating any control technology.

FGD technologies are, of course, the primary methods in use today for SO₂ control. There is sufficient experience with and data available on

FGD control systems in operation on which to base specific design applications. Further, FGD technologies are widely applicable to both new and existing coal and oil-fired boilers.

In searching for the most cost-effective approach to meeting environmental standards, the use of some form of coal cleaning in conjunction with FGD controls should be carefully considered. Users may find that coal cleaning can be used to reduce the size of the FGD control system needed. Thus, physically cleaned coal in combination with stack gas scrubbing may provide a definite overall cost advantage. (For more information, see Coal Cleaning with Scrubbing for Sulfur Control—An Engineering/Economic Summary, EPA-600/9-77-017.)

Under EPA sponsorship, TVA has been evaluating costs associated with six alternative sludge treatment/disposal systems:

- Untreated ponding
- Dravo process (two variations)
- IUCS process
- Chemfix process
- Untreated sludge-fly ash blending
- Landfill disposal of gypsum produced by forced oxidation of waste

The primary emphasis of the TVA work was not on the feasibility of the disposal technology, but rather on evaluating the relative economics of the disposal alternatives.

Results indicate that on a relative basis, the sludge treatment alternative involving forced oxidation of the sludge to gypsum requires the lowest capital investment and lowest total annual operating cost. This alternative requires a smaller capital investment than any other alternative except untreated ponding where the only major expense is the disposal pond. The selection of the forced oxidation alternative would require that a typical lime/limestone FGD system be modified (at some additional cost for capital equipment) to convert the raw FGD waste to gypsum. The studies also concluded that the alternatives involving pond disposal require higher capital investment than all landfill disposal alternatives.

The TVA-derived costs for the alternative FGD waste treatment processes do not take into account site-specific waste disposal conditions that a utility may encounter when selecting a system for installation. Results discussed here are based only on a set of pre-determined design and economic premises and should not be interpreted to represent a site-specific disposal situation. In the case of gypsum disposal, they are also based on a conceptual design only; there is little commercial experience.

The TVA-derived costs for FGD waste disposal range from \$5 to \$9/ton for direct ponding or landfilling operations. This estimate is well within the range for disposal of other solid wastes, such as sanitary landfill of municipal wastes or sanitary/chemical landfill of industrial wastes.

FBC waste

In the post-1985 period, as utilities invest in construction of new power plants, FBC technology may begin to displace the current dominance of FGD for SO₂ control. Although FBC shows promise for a cleaner-burning process, waste management will continue to be of concern because of the potentially large quantities of spent sorbent generated by the process. Preliminary estimates indicate that a typical 1000 megawatt FBC plant may generate as much as 730,000 tons of dry spent sorbent per year. That is over twice the amount of ash (300,000 tons) that would also be generated when burning coal containing about 3.5 percent sulfur and 12 percent ash. The amounts of spent sorbent generated by AFBC and PFBC systems are about the same.

The physical characteristics of FBC waste are quite different from the ash generated in conventional combustion processes. FBC waste consists primarily of the dry spent and unspent sorbent as well as the coal ashes from the bottom of the combustor. In addition, there is also some fly ash, which is removed from the flue gas by particulate control equipment. FBC waste is sometimes described as "soft ash" because it is only partially in the vitrified or glassy state. It is made up of soft granular particles, and, after being cured for several weeks, can be compacted and used for landfill.

The landfilling disposal option is being actively investigated to determine its environmental impact. It appears, at present, that FBC wastes may be disposed of in a sanitary type landfill operation with a minimum of environmental impact. Leaching tests have been carried out on FBC wastes and the results compared with standards for drinking water, because water standards for FBC waste have not yet been established. These results indicate that the leachate contains concentrations of calcium, sulfates, total dissolved solids and alkaline levels that exceed the standards. The concentration of trace metals in the leachate is below the standards.

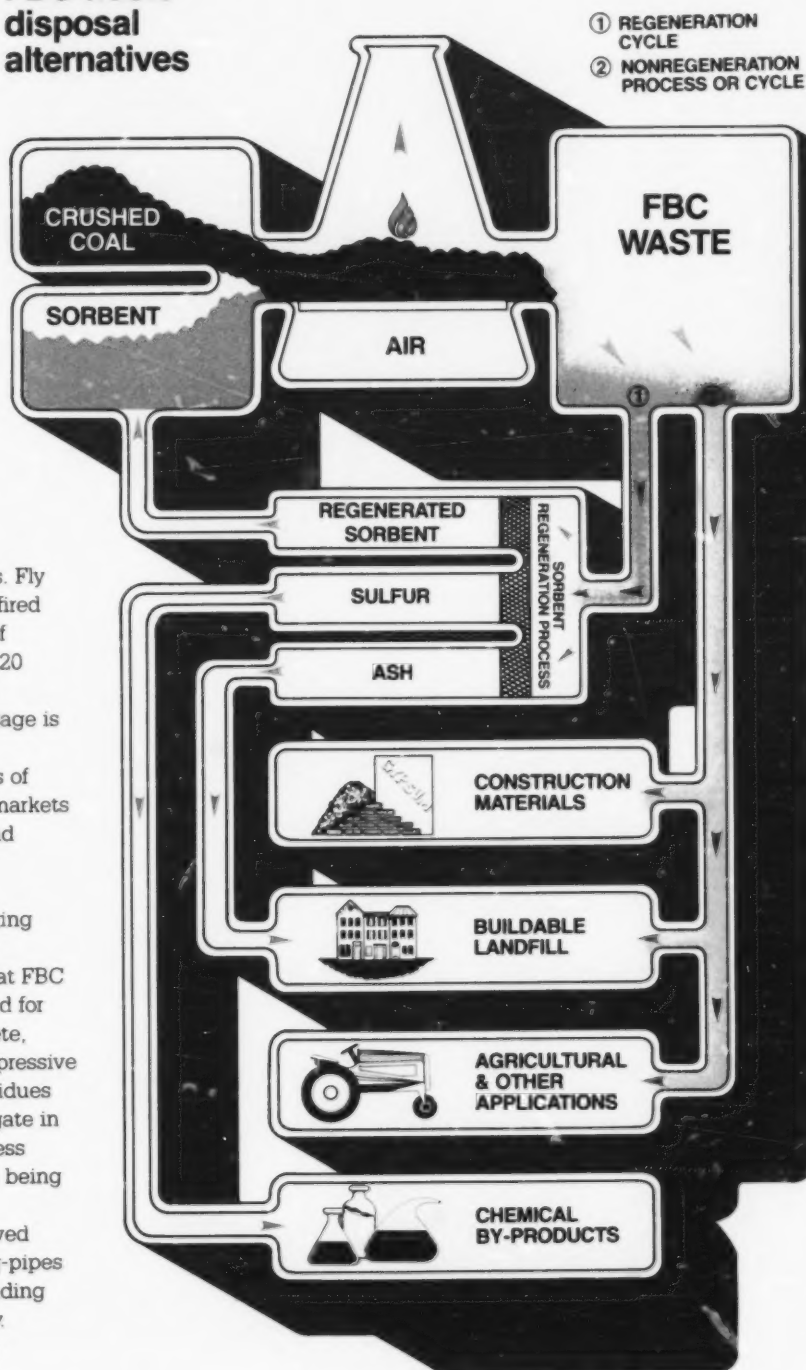
FBC waste disposal alternatives

At this point, however, there is no experience with FBC waste from any full-scale operational plant and considerable additional research is necessary to determine the actual environmental impact.

Commercial uses for FBC waste material are also being investigated—mostly under funding by DOE. The major obstacles to using the waste are the large volumes generated, transportation costs, and availability of competitive raw materials. Fly ash and bottom ash from conventional coal-fired power plants have been used in a number of products for years, but presently only about 20 percent of the total production is utilized. A summary of areas of potential FBC waste usage is presented in the accompanying table.

Because of the potentially large quantities of FBC waste material, one of the most likely markets is in the construction industry for use as road subbase, synthetic aggregate, or cement. Preliminary tests have been carried out to demonstrate the technical feasibility of making stable solid compacts and to determine the environmental impact. These tests show that FBC fly ash and waste sorbent can be substituted for small amounts of Portland cement in concrete, while maintaining the same or greater compressive strength as standard concrete. The FBC residues may replace up to 100 percent of the aggregate in asphalt and still maintain its strength. Process design and economics for these options are being developed.

Other possible new uses include autoclaved products such as bricks, hot press sintering-pipes and metal coatings; gypsum products including wallboard and plaster; and mineral recovery. Treatment of acid mine drainage is another potential use for FBC waste. A program is presently underway to evaluate the potential use of FBC waste as an FGD scrubbing reagent and as a stabilizing medium for FGD sludge. There are also programs currently at TVA and the U.S. Department of Agriculture on agricultural utilization of FBC wastes.



FGD waste treatment/disposal

DISPOSAL/TREATMENT ALTERNATIVES		DESCRIPTION	CURRENT STATUS	ADVANTAGES
DISPOSAL OPTIONS	PONDING	● untreated slurried solids pumped directly to a pond disposal	● one of two primary FGD disposal methods currently used	● minimizes operational processing and transportation ● minimum costs
	LANDFILL	● dewatered or chemically treated sludge is hauled to disposal site, or untreated slurries pumped there for dewatering or treatment ● dewatered material placed & compacted in excavated area	● same as ponding	● avoids land deterioration and water pollution associated with ponding
	MINE DISPOSAL	● treated or untreated FGD wastes deposited in depleted underground mines or dumped into surface mines	● under development and testing at controlled mine sites ● surface mine disposal being planned by several utilities	● transportation system already in place linking power plant & mine ● substantial capacity available ● potential for reducing acid drainage from mines ● minimizes subsidence (treated)
	OCEAN DISPOSAL	● bottom dump barge & slurry dispersion ● pipeline outfall ● various chemical & physical forms (soil or bricklike forms) ● outer continental shelf or ocean	● ocean dumping used for many years ● legislation prevents/limits dumping of harmful materials ● studies on environmental impact have halted practice	● could alleviate land use limits in converting plants to coal ● in chemically stabilized brick form, potential for artificial reef
TREATMENT METHODS	DEWATERING	● dry solids such as fly ash are added to slurry after settling and vacuum filtration, resulting in 70% solids waste	● currently in commercial use	● easy to use ● formulas can be varied to meet specific conditions ● suitable for landfill
	FORCED OXIDATION	● air is passed through slurry oxidizing the calcium sulfite waste into gypsum. Gypsum is dewatered to over 80% solids	● several pilot plants now in operation ● extensively used commercially in Japan	● upgrades waste for landfill ● potential for saleable by-product ● smaller volume than slurry
	CHEMICAL FIXATION	● several commercial processes that physically stabilize sludge and chemically fix it to reduce release of pollutants	● several processes commercially available and in use	● improved landfill characteristics ● decreased leaching potential
	REGENERATION	● several processes in which the absorbed SO₂ is removed as useable sulfur products (sulfuric acid or elemental sulfur) and the absorbent is recycled for reuse	● current commercial usage is extremely limited ● EPA considers Wellman-Lord process a demonstrated technology	● reduced waste volume ● reduced absorbent needed ● useable by-product recovered

Potential Utilization of FBC Waste construction

FBC ash residue for road-paving.

FBC ash and spent sorbent for cement and concrete.

Bricks from ash residue plus sodium silicate.

Ash residue for cement additive.

Wallboard composition, e.g., FBC ash-water-organic polymer.

Cement and concrete articles.

Filler on construction sites.

Soil stabilization.

Lightweight aggregate.

DISADVANTAGES	ECONOMIC FEASIBILITY	BY-PRODUCT(S)
● potential for ground water and surface water contamination ● degrades large quantities of land; difficult to reclaim	● currently offers low cost disposal ● long term land commitments could make it a costly approach in future	
● unless treated, waste is physically unstable and lacks compressive strength ● potential for leaching contaminants into ground & surface water	● lower capital investment than ponding ● higher annual operating costs than untreated ponding	
● potential for ground water contamination ● potential for surface water contamination (surface mines)		
● degradation of ocean environment for any untreated waste on the continental shelf or deep ocean		
● not as stable as chemical fixation	● somewhat higher annual operating costs than untreated	● nonbuildable landfill
● high fly ash content in by product ● leachate potential similar to untreated waste	● cement plants greatest market in U. S. ● wallboard market limited ● low capital investment and operating costs	● gypsum ● buildable landfill
● additional cost	● higher annual operating costs than untreated waste disposal	● buildable landfill
● liquid wastes require purging	● economic feasibility dependent on local conditions, markets, suppliers, etc.	● sulfuric acid ● elemental sulfur ● gaseous sulfur dioxide

extraction/separation of ash components

Hydrated lime, calcium sulfate, and ash residue for subsequent FBC reuse.

agriculture

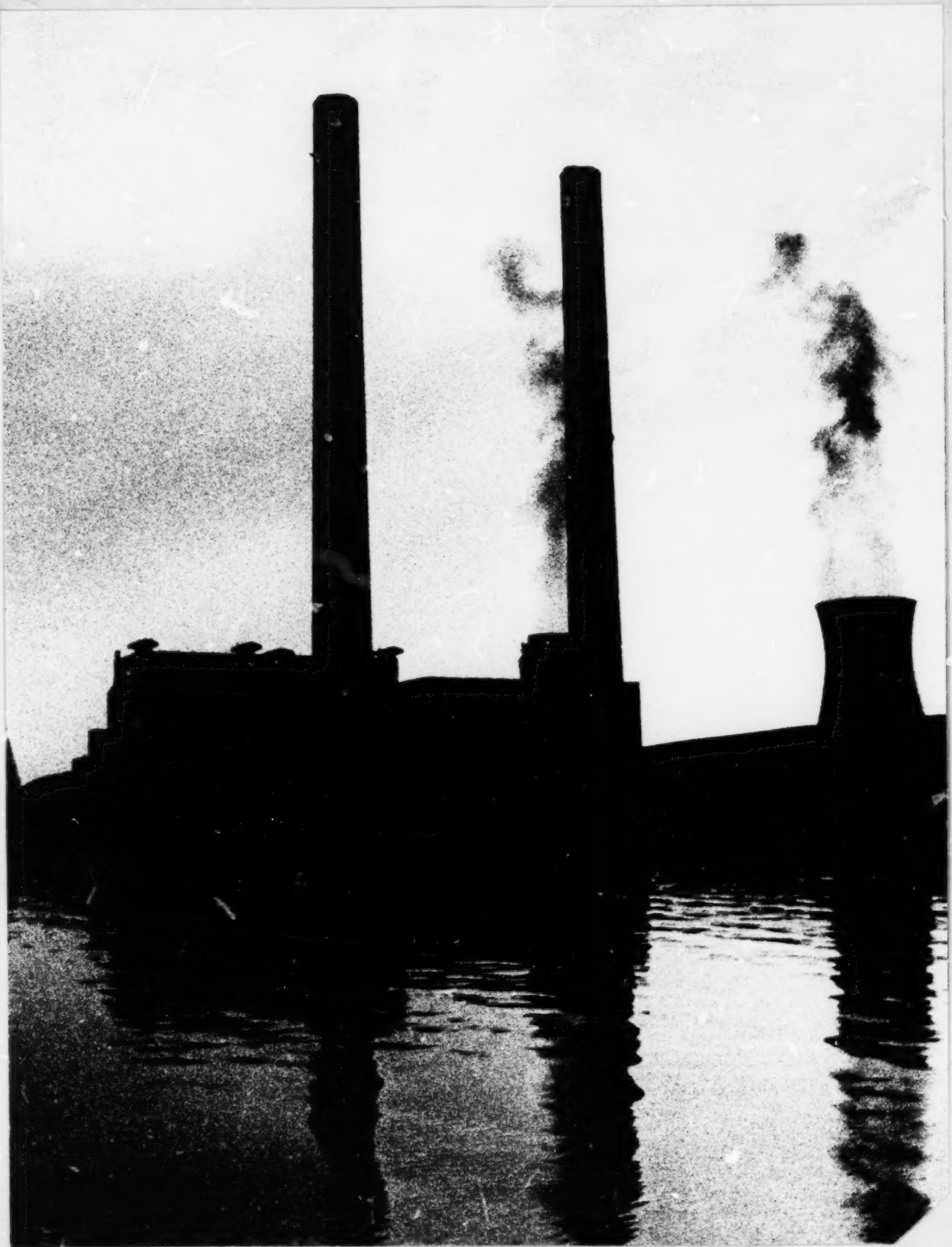
Soil conditioning, calcium sulfate extract, sintered FBC ash, fertilizer.

miscellaneous

Extraction of minor components, e.g., alumina as catalysts or catalyst supports.

Ion-exchangers as catalysts or catalyst supports.

Ion-exchangers as water purifiers; gas adsorbents.



status and outlook

U.S. industry—primarily the electrical utility industry—faces many difficult problems and decisions in complying with the SO₂ emission requirements of the Clean Air Act, as amended in 1977. The recently promulgated New Source Performance Standards, based on the use of best available technology for continuous emissions control, will mandate the application of SO₂ control technology to boilers burning low as well as high-sulfur coal. Because of the imminent increase in the installation of SO₂ control systems, much attention is being focused on the problem of managing the wastes generated by these systems.

The only commercially mature technology capable of meeting these standards for the near term is flue gas desulfurization. Choices will need to be made among the numerous FGD control processes currently available and among waste treatment, disposal, and utilization options. Various factors such as control effectiveness, operating reliability, waste characteristics, and economics must be considered in making a choice.

In the post-1985 period, FBC, an emerging alternate control technology, may have some advantages in terms of emissions control and relative ease of waste disposal.

current status FGD

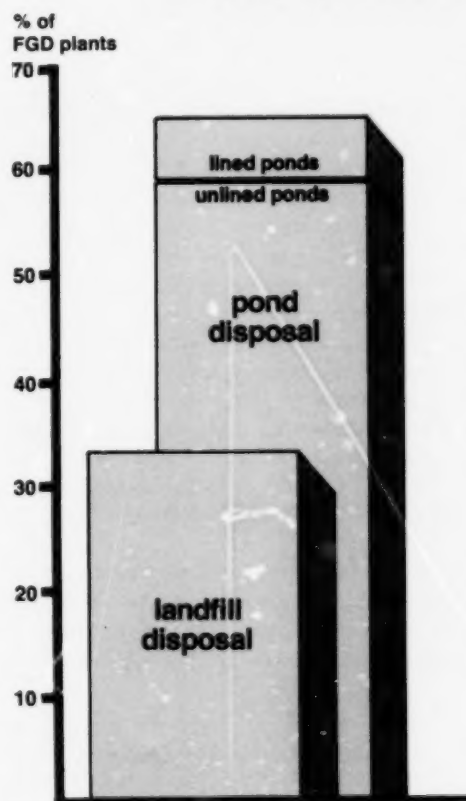
Of the approximately 30 utility power plants currently (early 1978) using some type of lime or limestone FGD control system, about two-thirds pond FGD wastes and one-third dispose of wastes by landfilling. About 90 percent of the plants ponding wastes use unlined ponds. Over two-thirds of all plants dispose of FGD wastes without any pre-treatment. Although a total of about 25,000 MW of FGD capacity was installed or under construction in 1978, the FGD waste disposal practices described here represent only those of the nearly 13,000 MW FGD capacity plants actually operating at that time. This operating FGD capacity represents about 6 percent of the total U.S. coal-fired capacity.

By comparison, Japan currently has about twice that percentage (11.5) of its steam electric capacity

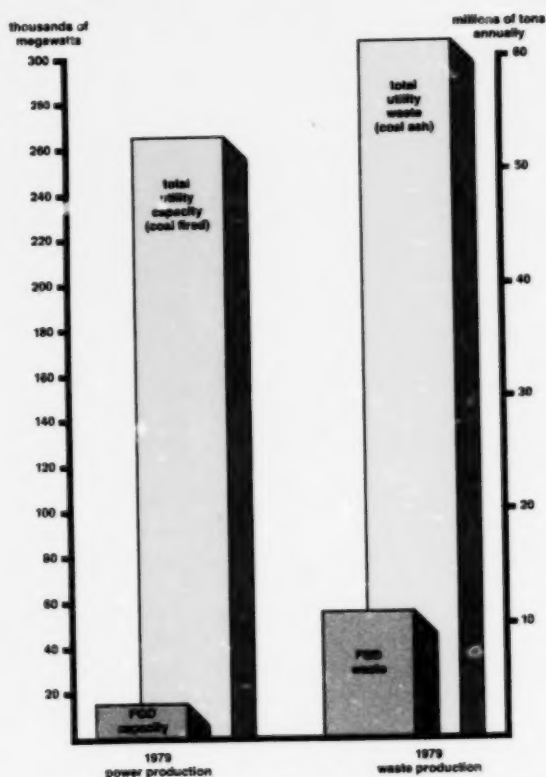
under FGD controls. Japanese FGD power plants under construction or planned, however, amount to only an additional 5 percent. This reflects Japan's rapid progress in application of FGD systems during the early 1970's, and the more recent slow down in their economy. Their experience with FGD operation and by-product utilization has been very successful.

In terms of megawatts of FGD capacities, rather than relative percentages of each country's steam electric generating capacities, the U.S. of course has a far greater total. This country's currently installed, under construction, and planned total FGD capacity amounts to about 55,000 MW. This compares to a total of about 14,000 MW for Japan.

current FGD waste disposal practices



current status: utility FGD control & waste



FGD and FBC waste disposal issues

As the FBC technology continues to develop, waste management concerns of FBC vis-a-vis conventional FGD practices are of growing interest. The waste disposal issues associated with FGD and FBC are similar in many respects. Of course, the FGD process differs significantly from FBC in design and operation, but a comparison can be made between FGD and FBC waste disposal issues. In making this comparison it must be noted that as of 1978 FGD systems were used in about 30 full-scale installations, while FBC systems are still in the developmental stage; a full-scale, integrated FBC unit waste disposal or regeneration operation has not yet been tested.

Land Use Impact—Comparisons of the volume of wastes and the land impact associated with disposal of solid wastes from FGD and FBC systems depend on several variable factors.

Among these are the amount of solids in the FGD waste, the calcium and sulfur ratio and gas velocity used in the FBC combustor, the amount of sulfur in the coal burned, and the compaction characteristics of the solid waste produced. Depending on the assumptions made for such FBC and FGD variables, one or the other technology can be shown to produce more solid wastes. Based on realistic assumptions, it can be concluded that the quantities of solid waste produced by FBC and conventional FGD systems are of the same order of magnitude.

The land impact, on the other hand, may be considerably different if the current practice of ponding of FGD waste is compared to direct landfilling of FBC wastes. Ponding of the FGD waste results in a commitment of this land for the operating life of the plant, whereas disposal of the dry FBC waste with successful reclamation of the land would not involve such a commitment. Forced oxidation, or other treatment of FGD waste, would allow landfill disposal and would reduce the land impact differences between FGD and FBC.

Disposal Options—Disposal options for both FBC and FGD are generally the same—mine, ocean and land (landfill or ponding) disposal. It is unlikely that the ocean disposal will be utilized, except for research. Mine disposal is a possible alternative, although it is sensitive to transportation costs involved. Presently, ponding is the major method for disposal of FGD sludge. Landfilling after treatment by one of several commercially available fixation methods is the preferred option for new FGD systems. FBC waste would also be disposed of in landfills.

By-Product Utilization—The projected uses of FBC waste are considerably greater than for FGD sludge. This is primarily due to the dry physical nature of FBC waste, some of which contains a high percentage of lime. The FGD sludge, on the other hand, can only be utilized for other applications after fixation treatment or oxidation. In the long run, market forces will determine the extent to which FBC waste and FGD sludge will be utilized.

Disposal Costs — Any cost comparison between FBC and FGD may be subject to considerable uncertainty, because there has not yet been a full-scale FBC waste disposal operation. However, based on estimates developed by TVA, it appears that the capital and annual operating disposal costs for FBC wastes will probably be similar to those incurred for the FGD-gypsum landfill operation.

outlook

It is clear that coal will have a key transitional role in the changeover from fossil fuels to sustainable or renewable energy sources. Improved environmental control technology and cleaner combustion processes will ameliorate the air pollution problems associated with the increased use of this fuel. FGD, coal cleaning, and FBC

technologies will increasingly be applied to new coal-fired power plants and industrial boilers.

Of the small percentage of coal-fired power plants that used FGD technology to control SO_2 emissions in 1978, less than half (about 4,500 MW) used any waste pre-treatment processing before disposal. It is clear that the waste problems associated with the expected increased use of control technologies will require more extensive waste disposal pre-treatment and more effective waste utilization approaches in the future.

Experience so far, both in the U.S. and abroad, has shown that environmental control techniques can be reliable and effective, and that the environmental impacts associated with combustion and control wastes can be maintained within acceptable limits.

**for
further
reading**

Advanced Fossil Fuels and the Environment, EPA Decision Series, EPA 600/9-77-013, Office of Energy, Minerals and Industry, Office of Research and Development, U. S. Environmental Protection Agency (June 1977).

This report reviews five major advanced fossil fuel processes and the control technologies being developed for them.

Economics of Disposal of Lime/Limestone Scrubbing Wastes: Untreated and Chemically Treated Wastes, EPA 600/7-78-023a, Industrial Environmental Research Laboratory, Office of Research and Development, U. S. Environmental Protection Agency and the Tennessee Valley Authority (February 1978).

A joint EPA-TVA study, conducted to provide detailed comparative economic evaluation of four alternatives available to the utility industry for disposal of waste produced from flue gas desulfurization systems, using limestone or lime slurry scrubbing. The four alternatives evaluated were untreated sludge and three different commercial processes for treating sludge. A 3.5 percent sulfur coal was used for all cases.

Energy/Environment II, EPA Decision Series, EPA 600/9-77-012, Office of Energy, Minerals and Industry, Office of Research and Development, U. S. Environmental Protection Agency (November 1977), pp. 137-147.

A joint EPA-TVA report summarizing the current program for the environmental management of effluents and solid wastes from steam-electric generating plants.

Sulfur Oxide Throwaway Sludge Evaluation Panel (SOTSEP), Volume I: Final Report—Executive Summary, EPA

650/2-75-010-a, Office of Research and Development, National Environmental Research Center, U. S. Environmental Protection Agency (April 1975).

This report presents the results of an intermedia evaluation of the environmental and economic factors associated with disposal or utilization of sludge from nonregenerable flue gas desulfurization processes. Although the report is rather technical, it does give one of the best overviews of the FGD sludge disposal/utilization problems.

Proceedings of the Symposia on Flue Gas Desulfurization,

Sponsored by the Industrial Environmental Research Laboratory, Office of Research and Development, U. S. Environmental Protection Agency.

Symposia are held annually and include a variety of technical papers from industry and government representatives which deal with the status of FGD technology in the United States and abroad. Subjects covered include: regenerable, nonregenerable, and advanced processes; process costs; and by-product disposal, utilization and marketing.

An Evaluation of the Disposal of Flue Gas Desulfurization Wastes in Mines and the Ocean: Initial Assessment, EPA 600/7-77-051,

Industrial Environmental Research Laboratory, Office of Research and Development, U. S. Environmental Protection Agency (May 1977).

An initial assessment of the environmental, technical, regulatory, and economic aspects of disposing FGD sludge in mines and in the ocean.

State-of-the-Art of FGD Sludge Fixation, EPRI FP-671, Project 786-1, Final Report, January 1978, prepared by Michael Baker, Jr., Inc., Beaver, Pennsylvania.

A comprehensive, up-to-date survey of all of the available FGD sludge fixation technology including details of technologies in current use at U. S. utilities.

Proceedings of the Fourth International Conference on Fluidized-Bed Combustion,

December 9-11, 1975, Sponsored by the U. S. Energy Research and Development Administration, Washington, D. C., Coordinated and Published by The Mitre Corporation, McLean, VA (May 1976).

Includes 38 technical papers from 7 sessions on the state of FBC technology. Areas covered include: Bench and lab-scale studies, pilot and demonstration plants, process problems, SO₂ absorption and regeneration, emission and control

technology, and commercialization prospects.

Controlling SO₂ Emissions from Coal-Fired Steam-Electric Generators, Volume II: Technical Discussion, EPA 600/7-78-044b (NTIS No. PB281100) March 1978.

This study supports a review by the EPA Office of Air Quality Planning and Standards, Office of Research and Development, Durham, North Carolina, of proposed New Source Performance Standards for sulfur dioxide emissions from coal-fired steam electric generators, considering three alternate strategies for removal of SO₂. It provides an assessment of technological, economic, and environmental impacts, projected to 1998, of the increased solid wastes resulting from the application of the various more-stringent controls as well as the current NSPS.

Effects of Setting New Source Performance Standards for Fluidized-Bed Combustion Systems, Final Report, March 1978,

Energy Resources Company Inc., Cambridge, Massachusetts 02138.

This study was undertaken for the U. S. Environmental Protection Agency to examine the potential consequences of revisions in New Source Performance Standards on fluidized-bed combustor based steam electric generators. It studied the appropriateness of differential effects of alternate regulatory approaches to the standards-setting process. An examination was made of the

potential benefits of fluidized-bed systems relative to conventional coal-fired systems equipped with FGD scrubbers.

Proceedings of the Fluidized Bed Combustion Technology Exchange Workshop, April 13-15,

1977, Sponsored by the U. S. Energy Research and Development Administration and the Electric Power Research Institute, The Mitre Corporation/Metrek Division, McLean, VA (August 1977).

This two volume set contains the technical papers from a six session workshop covering all aspects of FBC.

Sulfur in the Atmosphere: Proceedings of the International Symposium held in Dubrovnik, Yugoslavia, 7-14 September 1977.

Pergamon Press, Elmsford, New York. Visibility reduction, acid rain, possible effects on human health, and weather and climate modification are evidently associated with the reaction products rather than with SO₂ itself. Since the sulfate formation typically continues over a period of a day or more, the near field dispersion and maximum ground level concentration of primary pollutants were not considered in detail. Several invited and contributed papers focus on the size distribution and chemical composition of aerosol sulfur compounds, as well as on associated measurement and monitoring techniques.